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## CALCULATION OF PERTURBATION FACTORS FOR THE PTW 23343 MARKUS IONIZATION CHAMBER IN PROTON BEAMS\*

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In this work, perturbation factors for the PTW 23343 Markus ionization chamber in proton beams were determined using Monte Carlo simulations based on the MCNPX code in version of 2.7.0. The calculations were performed for chosen proton energies from 15 MeV to 80 MeV and for various energy spread. The main conclusion is that the perturbation factors for the considered ionization chamber cannot be neglected in the region with the disturbed proton equilibrium in the above-mentioned energy range.

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### 1. Introduction

This work is a continuation of our investigation concerning the clinical dosimetry in radiotherapy [1–5]. Perturbation factors are necessary in accurate proton therapy dosimetry using parallel plate Markus-type ionization chambers as well as cylindrical Framer-type ones. International dosimetry protocols recommend a value of unity of perturbation factors in water for Markus-type chambers [6, 7]. However, recent data published by various groups have indicated the contrary [8, 9]. In the specialist literature, there is a lack of an extensive data with perturbation factors for various ionization chambers for protons. This work is focused on calculations of proton perturbation factors in a 59.6 cm × 50.3 cm × 69.3 cm water phantom:  $p_{\text{wall}}$  — a factor related to scattering of protons in a wall of the chamber and  $p_{\text{cav}}$  — a factor connected with scattering of protons in an air cavity of the chamber. The knowledge of  $p_{\text{wall}}$  and  $p_{\text{cav}}$  makes it possible to estimate the overall perturbation factor  $p_Q = p_{\text{wall}} \times p_{\text{cav}}$ . The calculations were carried out for the PTW 23343 Markus ionization chamber for proton beams with various energy spectra. As a method, Monte Carlo simulations were used.

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## 2. Materials and method

All details of the construction of the PTW 23343 Markus ionization chamber were defined in the simulation program according to the physical Markus chamber specification (*i.e.* component materials: PMMA — 1.19 g/cm<sup>3</sup>, PE — 0.95 g/cm<sup>3</sup> [10]). The calculations were performed for the dry air. The perturbation factors denoted in a generally accepted manner as  $p_{\text{wall}}$  and  $p_{\text{cav}}$  were determined by means of Monte Carlo simulations based on the MCNPX code in version of 2.7.0.  $p_{\text{wall}}$  is the factor that corrects the response of an ionization chamber for the non-water equivalence of the chamber wall.  $p_{\text{cav}}$  is the factor that corrects the response of an ionization chamber for effects related to the air cavity making the proton fluence inside the cavity different from that in the medium in the absence of the cavity. The water-equivalent thickness of the chamber wall was taken into account when evaluating the depths at which the ionization chamber was positioned. The reference point of the ionization chamber location was taken to be on the inner surface of the entrance window, at the centre of the window. Perturbation factors were determined at depths around the Bragg peak *i.e.* in the region with the disturbed proton equilibrium where according to the Spencer–Attix theory, there is no the secondary electron equilibrium inside the small detectors and the radiation fluence is particularly sensitive to the ionization chamber presence.

## 3. Results and discussion

The calculations were performed for the chosen proton energies of 15 MeV (Figs. 1 (a), 2 (a)), 30 MeV (Figs. 1 (b), 2 (b)), 60 MeV (Figs. 1 (c), 2 (c)), 80 MeV (Figs. 1 (d), 2 (d)), for monoenergetic beams as well as for beams with energy spreads — FWHM = 0.5 MeV and 3 MeV. Such choice of proton energies makes it possible to show an influence of the beam spectrum on values of  $p_{\text{wall}}$  and  $p_{\text{cav}}$ . The simulated primary proton beams had no spatial spread. The change of the overall perturbation factor around the Bragg peak for protons of 60 MeV is presented in Fig. 3.

The number of primary protons in each simulation was between  $5 \times 10^6$  for 15 MeV protons and  $3 \times 10^7$  for 80 MeV protons. It was chosen in such a manner as to reach the perturbation factor uncertainty less than 0.4% (one standard deviation level). The perturbation factors become different from 1 in the region with the disturbed proton equilibrium. They depend strongly on proton spectra. Generally, the values of  $p_{\text{wall}}$  are less than 1 whereas values of  $p_{\text{cav}}$  are greater than 1.  $p_{\text{wall}}$  becomes less for the smaller proton energy and the smaller energy spread. Its decrease is particularly visible at depths after the Bragg peak. In the case of  $p_{\text{cav}}$ , the increase of its value begins before the Bragg peak. The maximum of  $p_{\text{cav}}$  appears at the depths

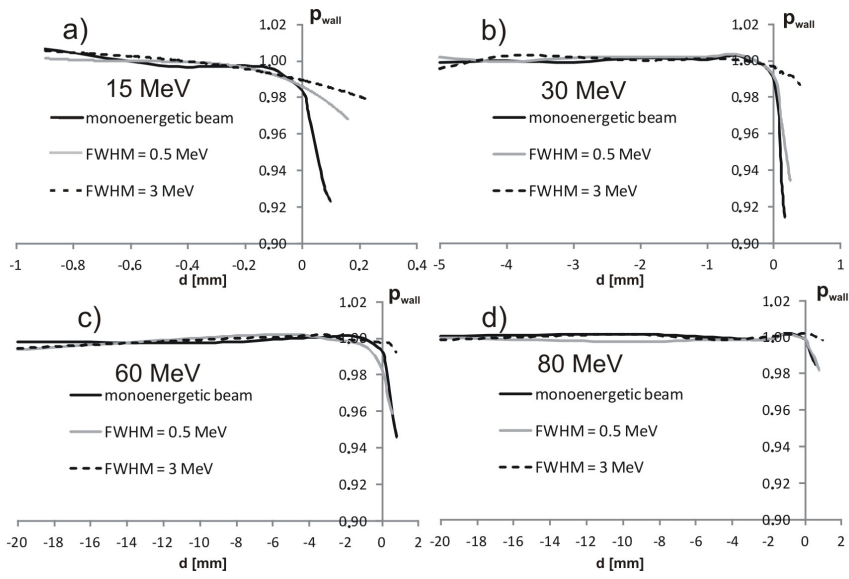


Fig. 1. The perturbation factor  $p_{\text{wall}}$  versus the distance  $d$  from the Bragg peak. The negative values of  $d$  determine this distance before the Bragg peak, whereas the positive ones are related to the region beyond the Bragg peak.

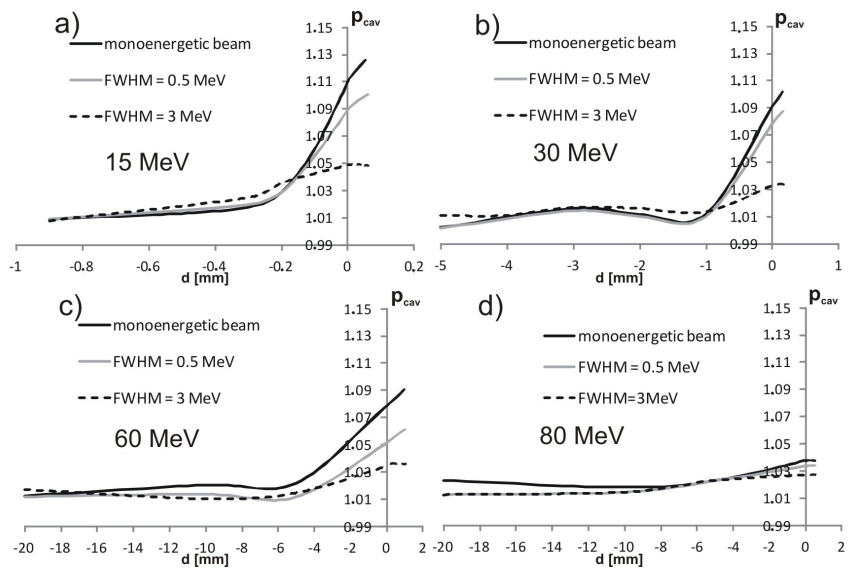


Fig. 2. The perturbation factor  $p_{\text{cav}}$  versus the distance  $d$  from the Bragg peak. Otherwise as in Fig. 1.

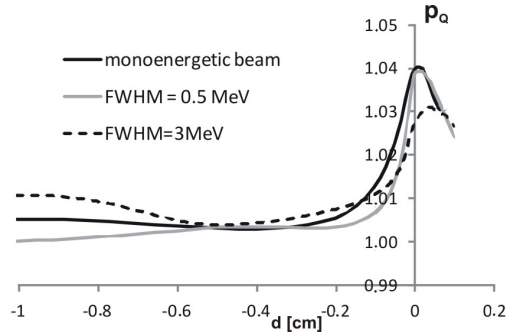


Fig. 3. The overall perturbation factor  $p_Q$  versus the distance  $d$  from the Bragg peak. Otherwise as in Fig. 1.

somewhat after the Bragg peak. The change of the values of  $p_{\text{cav}}$  is greater for smaller energy and for monoenergetic protons. The overall perturbation factor  $p_Q$  is slightly affected by the proton energy spread.

#### 4. Conclusions

This work has shown that the perturbation factors  $p_{\text{wall}}$  and  $p_{\text{cav}}$  for the PTW 23343 Markus ionization chamber for protons with energies from 15 MeV to 80 MeV cannot be neglected in the region with the disturbed proton equilibrium. The fact that the values of  $p_{\text{wall}}$  are below 1, whereas the values of  $p_{\text{cav}}$  are greater than 1, makes the overall perturbation factor  $p_Q$  closer to 1 than  $p_{\text{wall}}$  and  $p_{\text{cav}}$  separately. All presented results in a numerical form are available for common use, because of their practical values. They will be sent to users after forwarding e-mail message to the authors of this paper.

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